AN IMPROVED OFFSET GENERATOR DEVELOPED FOR ALLAN DEVIATION MEASUREMENT OF ULTRA STABLE FREQUENCY STANDARDS*

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Abstract

Measuring the performance of ultra stable frequency standards such as the Superconducting Cavity Maser Oscillator (SCMO) will necessitate improvement of some test instrumentation. The frequency stability test equipment used at JPL includes a 1 Hz Offset Generator to generate a beat frequency between a pair of 100 MHz signals that are being compared. The noise floor of the measurement system using the current Offset Generator (1.7×10^{-14} at 1 second tau and 6.2×10^{-17} at 1000 seconds), is adequate to characterize stability of hydrogen masers, but will not be for the SCMO. A new Offset Generator with improved stability has been designed and tested at JPL. With this Offset Generator, and a new Zero Crossing Detector recently developed at JPL, the measurement floor has been reduced by a factor of 5.5 at 1 second tau, 3.0 at 1000 seconds, and 9.4 at 10000 seconds, compared against the previous design. In addition to the new circuit designs of the Offset Generator and Zero Crossing Detector, tighter control of the measurement equipment environment has been required to achieve this improvement. The design of this new Offset Generator will be described, along with details of the environment control methods used.

INTRODUCTION

Allan Deviation measurements made at the Jet Propulsion Laboratories Frequency Standards Laboratory require an offset generator to test some types of equipment. The offset generator is used, for example, to test a frequency source when neither the measurement device or the frequency reference can be offset to obtain a 1 Hz beat for the zero crossing detector [1]. It is also used to test 2-port devices. A single 100 MHz reference carrier is split into two paths, with one path to the zero crossing detector containing the 2-port device in test, and the other path containing the offset generator to develop the 1 Hz beat signal for the zero crossing detector. Figure 1 shows the instrumentation used to perform these tests.

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OFFSET GENERATOR DESIGN

A block diagram of the offset generator is shown in Figure 2. The 1 Hz offset is generated in two steps, using divide and mix direct frequency synthesis to first develop a -10 Khz offset in the input stage, then a $+9.999$ KHz offset in the output stage. The input stage translates the input frequency by a factor of $1-10^{-4}$, and the output stage by a factor of $1+10^{-4}$ so that $F(out) = F(in) \times (1 - 10^{-4}) \times (1 + 10^{-4}) = 99.999999$ MHz. The output of each stage is taken from a phase locked crystal VCO acting as a narrow band output filter to minimize the spurious frequency products in the offset generator output.

OFFSET GENERATOR PERFORMANCE

Performance of the present day offset generator is adequate to measure stability of frequency standards in current use in the NASA/JPL Deep Space Network. Stability of the offset generator is compared against a hydrogen maser stability in Figure 3. Future requirements for the Deep Space Network specify tighter frequency stability limits than these present frequency standards can supply **[2]**. To test to these tighter standards in the future, and the very high stability fiber optic reference signal transportation links in current use by the Deep Space Network, some design changes have been made in the test instrumentation. A recent redesign of the zero crossing detector has improved it's stability **[3]**. At the same time, a fiber optic interface to the frequency counter and computer has been added to eliminate ground loops, and reduce crosstalk between channels in the measurement system.

OFFSET GENERATOR NOISE

During static environmental conditions, the primary elements that establish frequency stability of the offset generator are the local oscillator VCO and PLL elements, and the frequency dividers. At frequencies within the phase lock loop bandwidth, the VCO tracks the signal in test, canceling VCO phase instability, but not amplitude instability. AM to PM noise conversion that occurs in the zero crossing detector mixer [4],[5] will generate an additive phase instability in the measurement system.

The measured power spectral density of AM and PM noise of the 100 MHz VCO are plotted in Figure 4a. The calculated closed loop phase noise with a 100 Hz loop bandwidth, and the AM to PM converted noise generated in a mixer with a -30 dB AM to PM conversion coefficient are also shown on the same figure. The AM to PM converted noise is shown to predominate over closed loop VCO PM noise at offset frequencies below 4 Hz. Oscillator AM noise therefore appears to be a major factor in establishing long term stability of the offset generator.

1. Oscillator Redesign

In the redesign, the original oscillator has been replaced with a low noise 5 MHz BVA crystal oscillator followed by a X20 frequency multiplier. The plot of Figure 4b shows the measured and calculated noise performance improvement of this new oscillator/multiplier tested under the same conditions, and using the same loop bandwidth as for Figure 4a. At 1 Hz offset frequency, AM noise and PM noise have been reduced 20 dB and 40 dB respectively, below the original oscillator.

The oscillator/multiplier for the output frequency conversion is offset 0.05 Hz from nominal at 5 MHz, allowing use of an available, production 5 MHz VCO. The input frequency conversion requires a 500 Hz offset at 5 MHz, well beyond the pulling range of any available high precision 5 MHz VCO.

2. Single Sideband Mixer

To avoid a custom design for the input converter VCO, a single sideband mixer is used to suppress the input carrier in place of using a phase locked VCO. The unwanted sideband and input carrier are attenuated more than 45 dB below the output by adjusting amplitude and phase balance of the low frequency input to the mixers. The phase lock loop of the output conversion section further attenuates these unwanted frequency components to more than 110 dB below the output carrier of the offset generator. Figure 5 shows the basic design of the single sideband mixer.

3. Frequency Dividers

The frequency dividers are of conventional design, using an ECL divide-by 40 for the first divider, followed by HC74 series TTL dividers for the remaining lower frequency division of 250.

4. Environmental controls

At long measurement times where the stability approaches parts in 10^{-18}, the offset generator is affected by temperature variations, vibration, and relative humidity that can mask any improvements made in the electronics. The offset generator and zero crossing detector are both installed in a thermoelectric temperature controlled enclosure to reduce this sensitivity. The temperature control is set at 25 Celsius, and a thermal gain of 20 has been realized. The electronics are on a 1/2 inch thick aluminum coldplate coupled to the thermoelectric elements for heat transfer. The large mass of the coldplate serves also to reduce the mechanical resonant frequency of the assembly, which reduces sensitivity to shock and vibration. Further investigation is required to determine the best approach to reduce sensitivity to humidity.

5. Test Results

Allan Deviation of the original, and the revised designs of offset generator and zero crossing detector are compared in Figure 6. The new offset generator and zero crossing detector reduces the measurement noise floor by a factor of 5.5 at a tau of 1 second, 3.0 at 1000 seconds, and 9.4 at 10000 seconds.

CONCLUSIONS

Improvements have been made in the measurement floor of the Allan Deviation test equipment by replacing the crystal VCOs used in the offset generator with a lower noise 5 MHz crystal VCO and X20 frequency multiplier for one stage of the offset generator, and a single sideband mixer in place of a phase locked VCO to reduce spurious outputs in the other stage. Adding a thermoelectric temperature controller to the electronics has further improved stability by reducing temperature variations of the electronics by a factor of 20.

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[4] *"RF and Microwave Phase Noise Measurement Seminar,"* Hewlett Packard, Jan.1987.

[5] *"Frequency Synthesizer Theory and Design,"*, Third Edition," Vadim Manassewitsch, John Wiley & Sons, Inc. 1987.

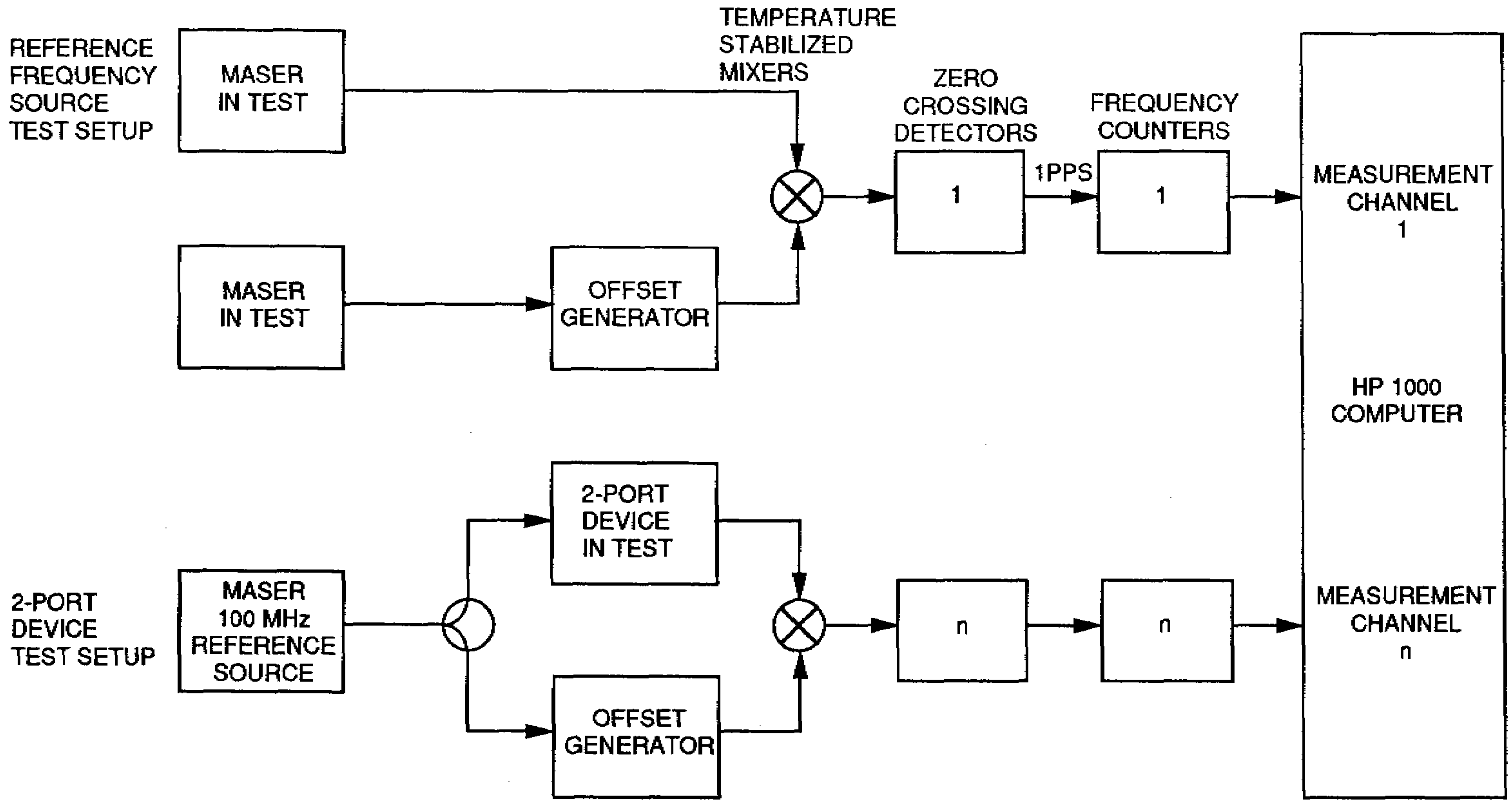
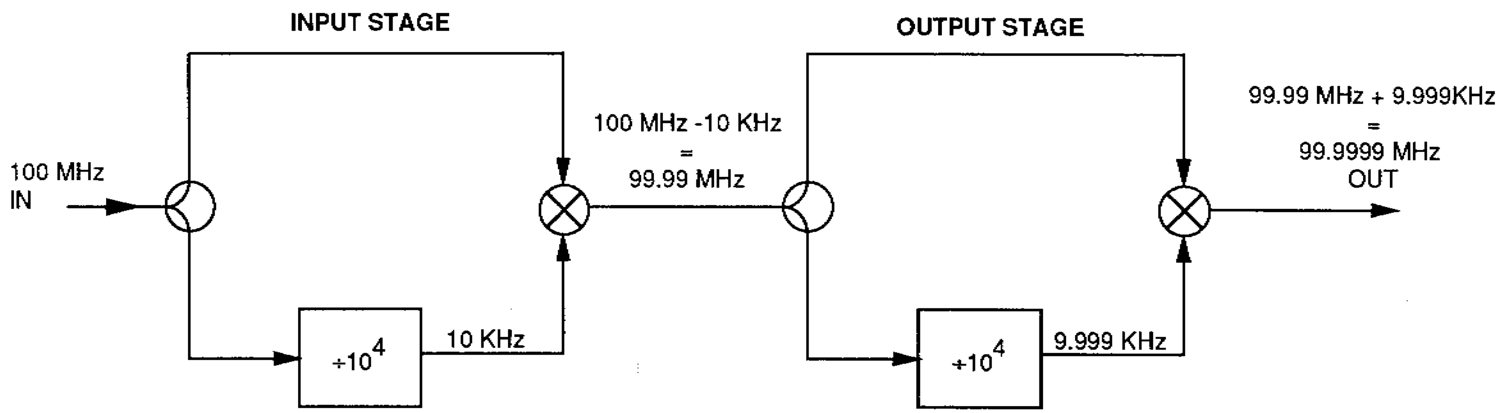
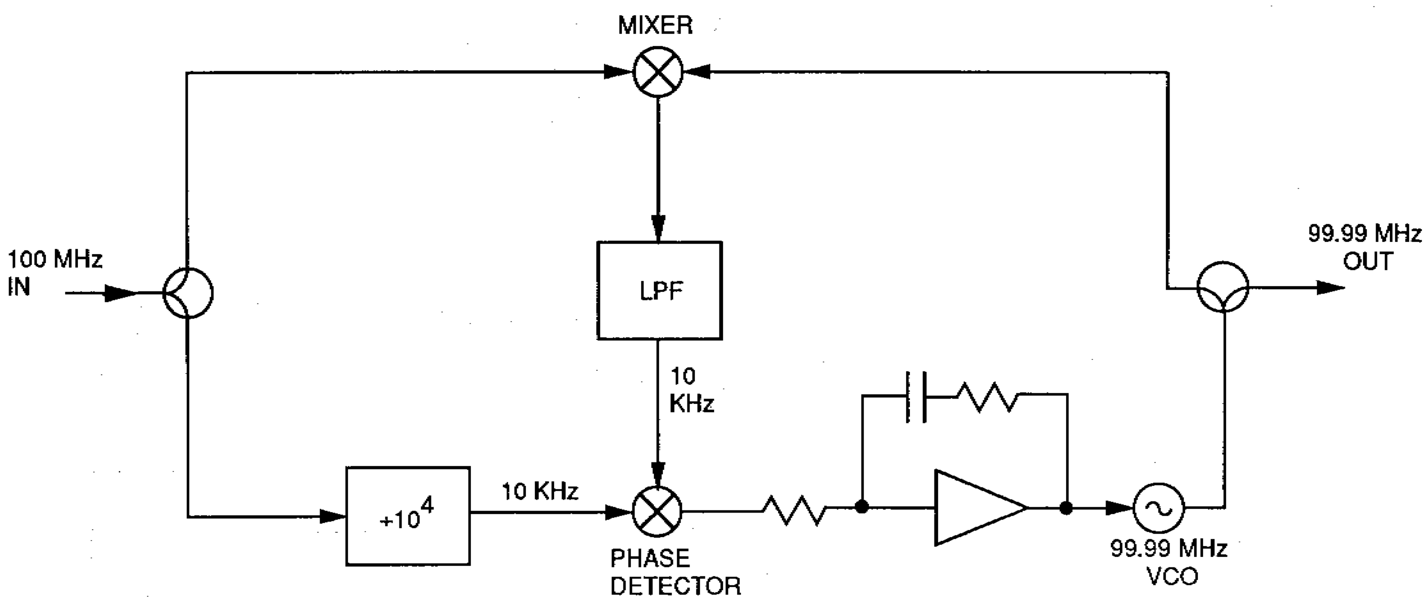


FIGURE 1

ALLAN DEVIATION TEST INSTRUMENTATION



GENERAL BLOCK DIAGRAM



INPUT STAGE DETAILED DIAGRAM

FIGURE 2

OFFSET GENERATOR BLOCK DIAGRAM

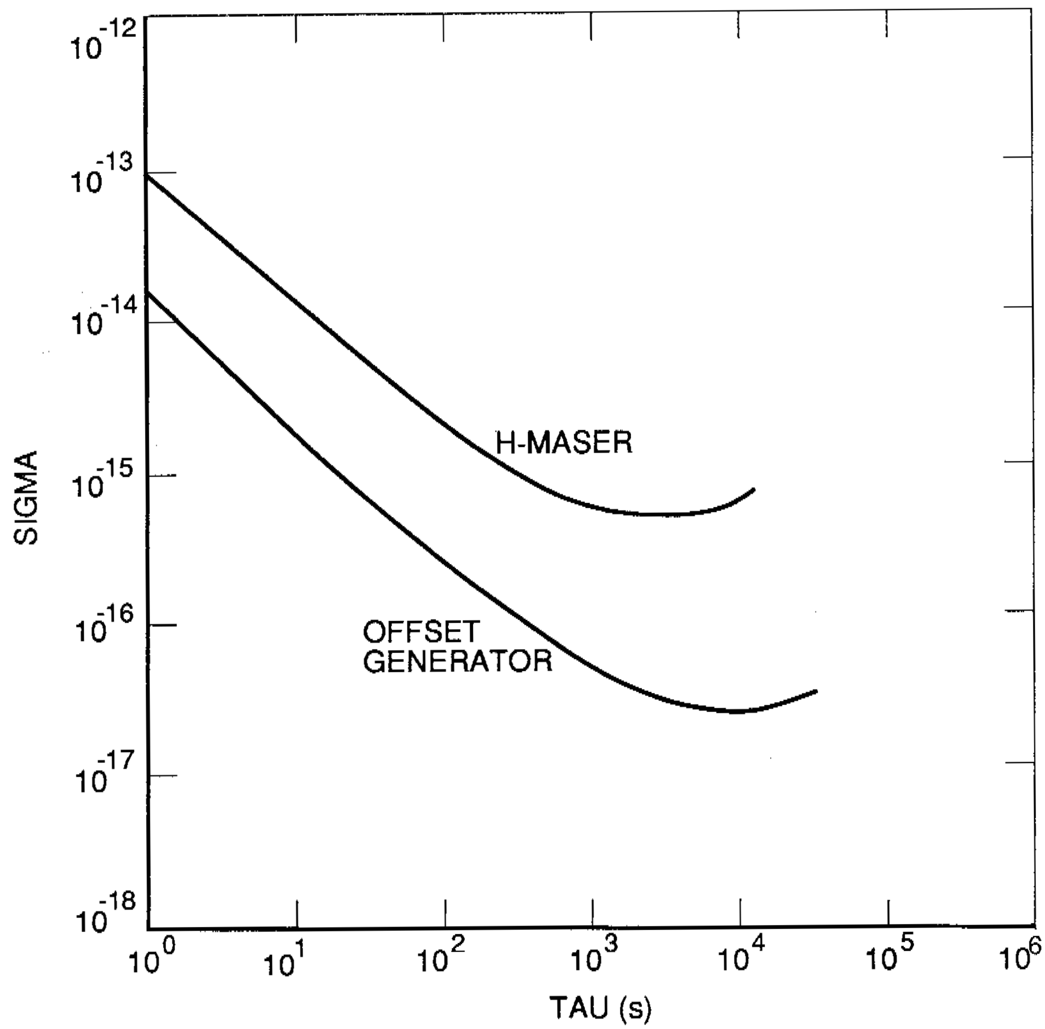


FIGURE 3

ALLAN DEVIATION
HYDROGEN MASER
AND
ORIGINAL OFFSET GENERATOR

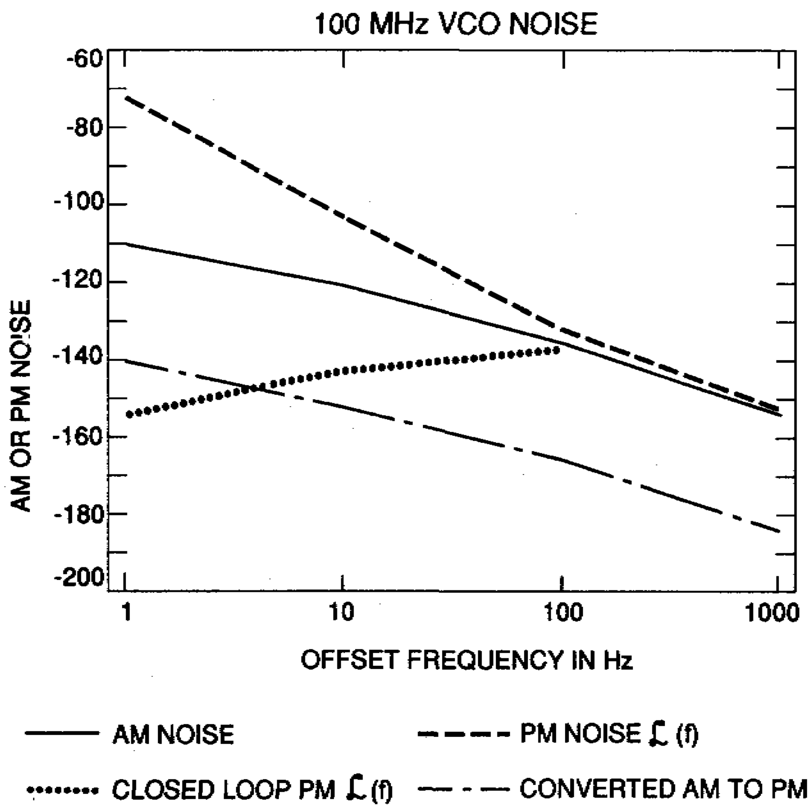


FIGURE 4a

AM AND PM NOISE
100 MHz VCO

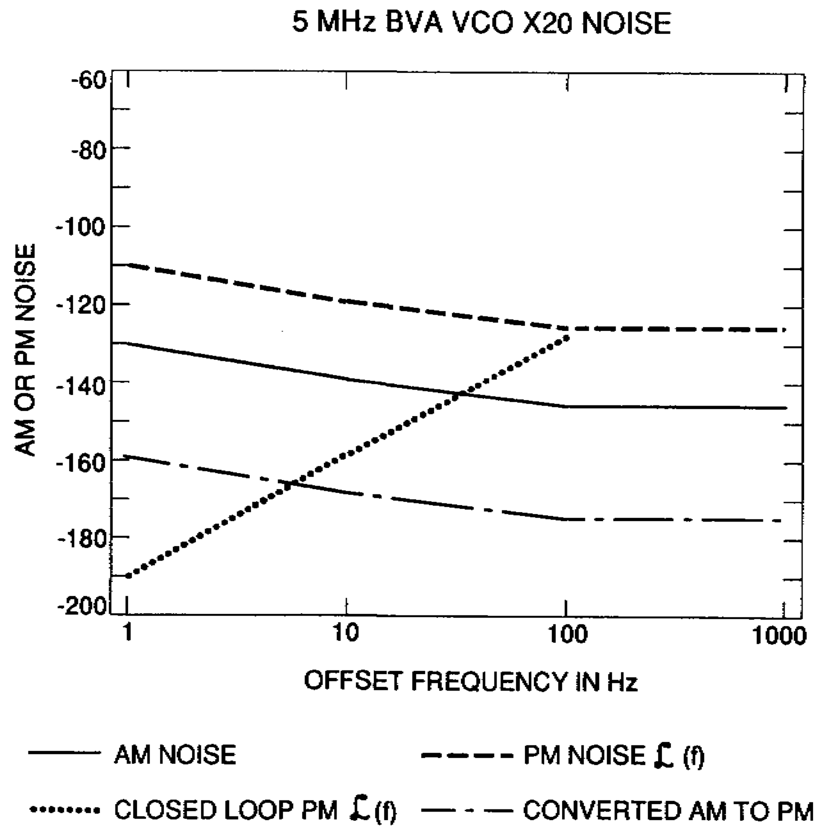


FIGURE 4b

AM AND PM NOISE
5 MHz BVA VCO/x20 MULT.

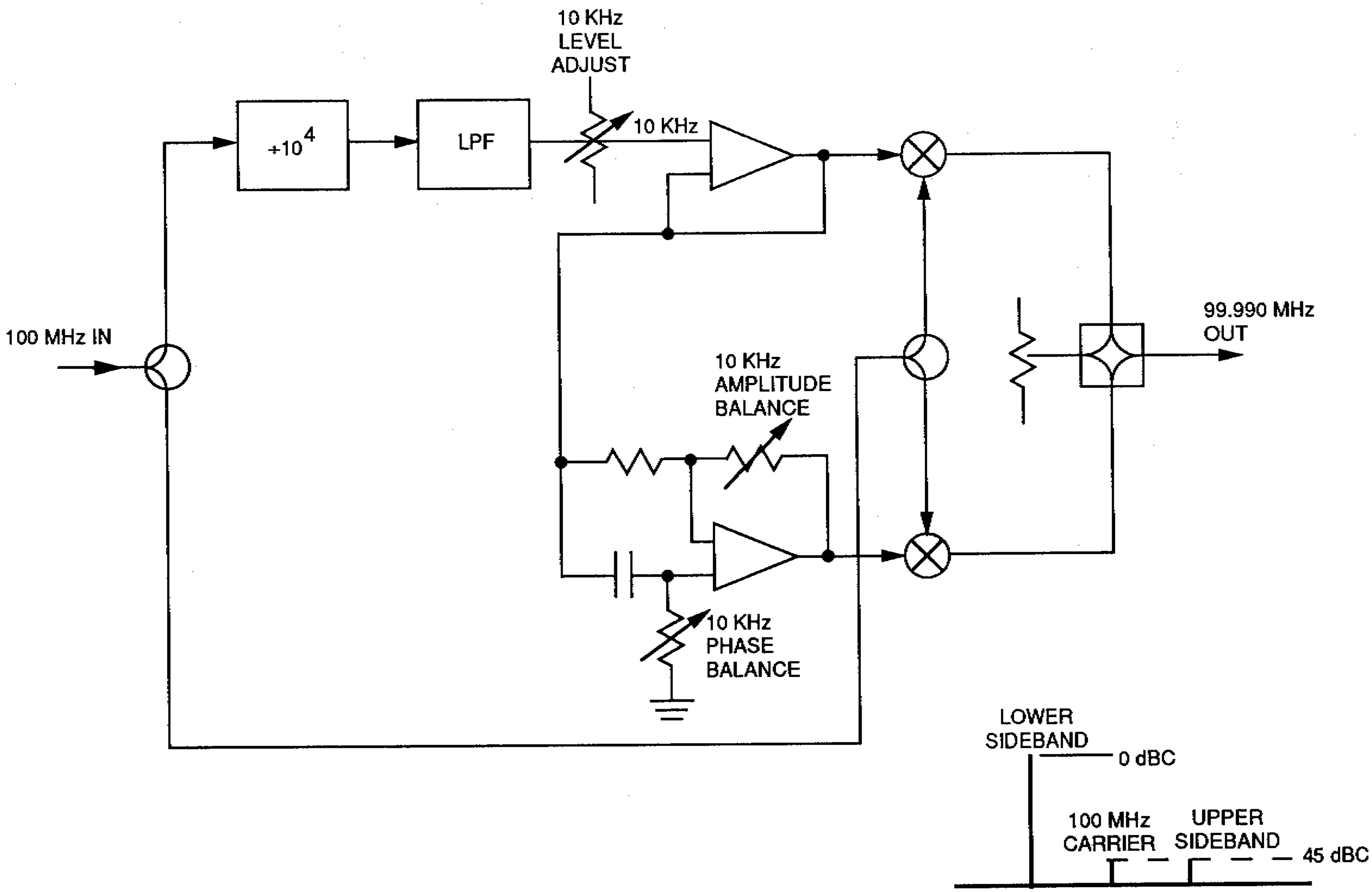


FIGURE 5
SINGLE SIDEBAND MIXER BLOCK DIAGRAM

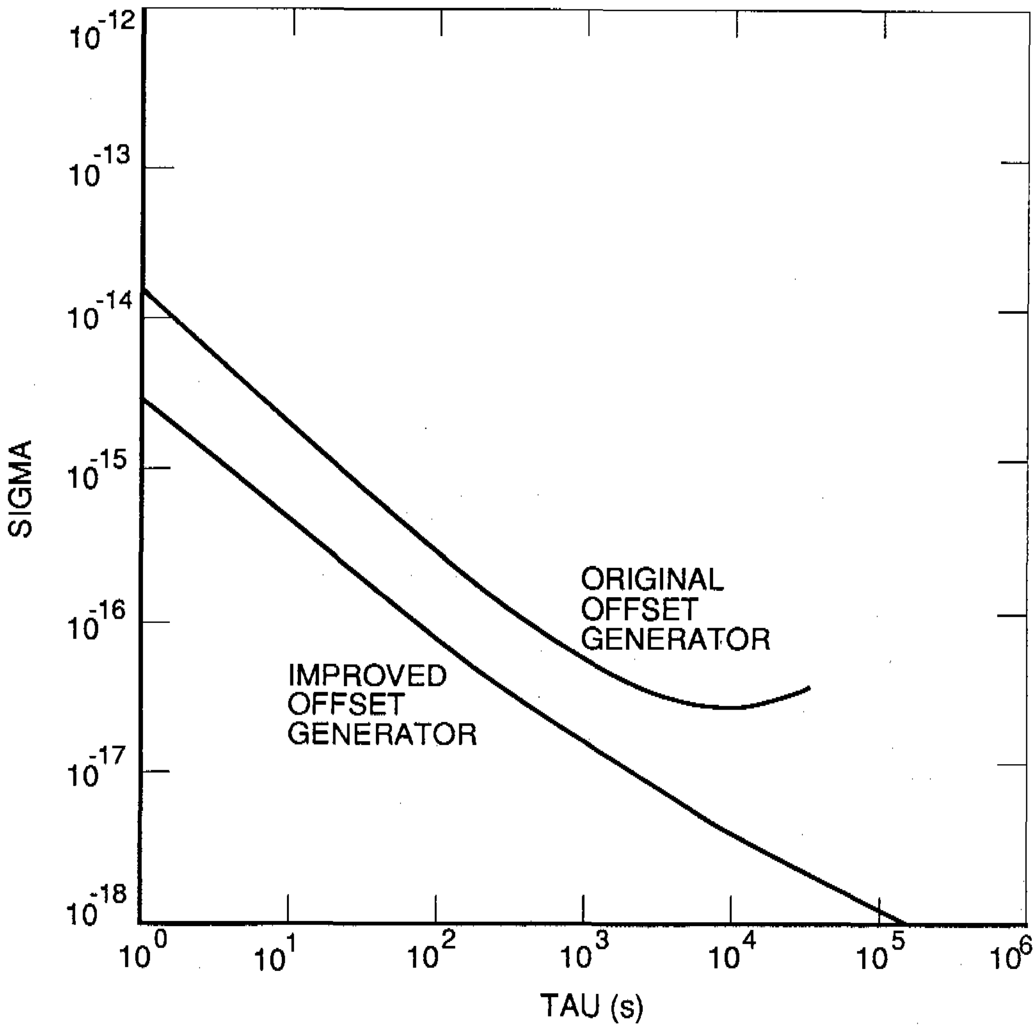


FIGURE 6

ALLAN DEVIATION ORIGINAL
vs IMPROVED OFFSET GENERATOR